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LOCKHEED NUCLEAR PRODUCTS

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Marietta, Ga.

FOREWORD

This quarterly report is submitted to the Office of Space Launch Vehicles of the National Aeronautics and Space Administration in accordance with the requirements of NASA Contract NASw-114.

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1 INTRODUCTION AND SUMMARY

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This report describes the progress made during the quarter, October through December 1963, on Contract NASw-114.

Investigation of the failure of nuclear instrumentation in the test loops continued during the period. A discussion of the failure is found in Section 2, Equipment. Temperature correlation measurements were obtained from an instrumented titantium test specimen.

Erratic behavior of the refrigeration system expansion engines is being evaluated.

The Mallory 1000 shield stud and plug were successfully modified by remote handling techniques.

Modification to the test loop carriages continued throughout the period. A new chevron seal, made of polyurethane, was conceived, designed and fabricated for the beam port.

Flux measurements were made in HB-2 reactor beam port at varying reactor operating conditions and different rod positions to better evaluate the time required to achieve an integrated dose of 1×10^{17} nvt fast neutrons ($>$ 0.5 Mev) for in-pile tests.

Both in-pile and out-of-pile test data were obtained on several materials during the period.

Author

2 EQUIPMENT

2.1 TEST LOOPS

The fission chambers in the test loops have not provided consistent measurement of the fast neutron flux due to the presence of moisture which reduced the resistance across the high voltage line to a level at which reliable readings could not be obtained. This moisture, in several instances, stemmed from water leaking into the stainless steel tubes carrying the instrument lines. The leaks were repaired and the tubes were evacuated to remove any residual moisture. The fission chamber tube was then filled with dry nitrogen and sealed. Repairs by this method proved satisfactory for eight (8) test cycles for one test loop; a second test loop became inoperative during the initial test cycle. In both instances, the fission chamber signal had become too erratic to be considered reliable. The indication is that other minute leaks in the stainless steel tubes have developed, admitting moisture to the instrument lines. All other instrumentation equipment continues to operate normally.

The malfunction of the fission chambers in the test loops necessitated other means of determining the integrated dose received by each test specimen. This was accomplished by using data from flux measurements obtained by the irradiation of foils with activation energies selected to provide the fast neutron flux level at the test position. These measurements were taken at various intervals during the reactor cycle. This method has been suitable so far since reactor core lattice configuration has been stable and flux distribution has not been influenced by the presence of other experimental equipment.

The polyurethane seals used in the joint between the test loop head assembly and the remainder of the test loop have withstood exposures to fast neutrons equivalent to an exposure as great as 1.9×10^{17} nvt at energy levels greater than 0.5 Mev at the test specimen position. It is interesting to note that while the sealing faces are serrated before irradiation, these surfaces are found to be smooth after irradiation. The early seals, which were of cast gum, exhibited minor brittleness after exposure and minor swelling causing some difficulty in removal from the seal groove. The latest seals, made from millable gum stock, have exhibited greater swelling tendencies but are not brittle after irradiation. Both types of seals provide adequate sealing even though they have reduced strength as a result of irradiation.

Extensive experience has been gained in the remote specimen changing and minor repair techniques used on test loops in the hot cave. Thermocouple extension wires have been joined, instrument leads in the test loop head assembly repaired, Heli Coil inserts replaced, and a screw broken off below the surface of the head has been extracted using remote handling techniques. Equipment changes and repairs such as these have increased the utility value of the hot cave, and movement of the test loop to the hot laboratory area outside of the containment vessel for shop repairs has not been required as yet.

A line has been added to the test loop to provide continuous evacuation of the vacuum insulation annulus of the helium transfer lines within each loop. This line was added since, after several test cycles, it was noted that each loop was requiring increased refrigeration capacity to control specimen temperature. A temporary line was connected to a test loop to check the condition of the vacuum chamber, and the internal pressure was considerably higher than before irradiation. The lines were then evacuated continuously during the next several test cycles.

An increase of internal line pressure, during warm-up of the lines after removal of the loop from the beam port, followed by a decrease of internal pressure was observed. This action has not as yet been explained. However, the addition of a line to each loop to provide continuous evacuation during this period allows adequate control of the insulating vacuum.

2.2 TEMPERATURE CONTROL CALIBRATION

The sensing elements which control the specimen temperature are platinum resistance thermometers, which are quite sensitive to radiation damage. For this reason they are located out-of-pile on the inlet and outlet legs of the vacuum insulated refrigerant transfer lines that supply cold helium to the test loops. Since there is no direct measurement of the specimen temperature during testing, the temperature control system was correlated with a direct measurement of temperature at the test location. This correlation consisted of three steps: calibration of the direct measurement equipment, determination of the temperature distribution across the test specimen gage length, and determination of the correction to be applied to the control sensors to insure the $30^{o}R$ temperature in the test specimens.

The procedure developed for each of these three steps was used in the preceding quarter establish temperature control conditions for stainless steel specimens. Since it was again used during the period covered by this report to establish control conditions for titanium alloy specimens, the method is briefly reviewed.

A test specimen, in this case a titanium alloy (6% Al 4% V) specimen, was instrumented with three copper-constantan thermocouples. These thermocouples, made from wire tested for homogeneity as outlined in Quarterly Report #7, Page 4, were attached at each end of the gage length and at the midpoint of the gage length, at positions shown in Figure 4 by the method described in Quarterly Report #7, Page 15.

In the first step, the calibration of these thermocouples, the instrumented specimen and a NBS calibrated resistance thermometer were included in a package wrapped in aluminum foil to provide a common temperature for the instrumented specimen and the resistance bulb reference standard. A fourth thermocouple, not included in the package, was used to measure environmental temperature. The package was placed in test loop 201-004 and the refrigeration system was used to provide a flow of cold helium around the package. The helium guides used during this calibration were modified to accept the abnormal bulk of the package. The temperature of the test loop was stabilized at various levels between 30°R and 400°R while simultaneous recordings were made of the temperature measured with the resistance thermometer and the emf output of the thermocouples. An additional comparison of the thermocouples and the resistance thermometer was made by immersing the package in liquid nitrogen to check the test procedure at a known standard temperature. Calibration curves for the three specimen thermocouples are given in Figures 1, 2 and 3. Correction factors to convert the thermocouples' output to standard reference table emf values are given in Figure 4.

The second step in the procedure, the measurement of the temperature gradient across a titanium alloy (6% Al, 4% V) specimen, was done after the thermocouple calibration had been completed. For this measurement, the platinum resistance thermometer was removed allowing only the instrumented test specimen to remain in the test position in loop 201-004. The test loop temperature was stabilized in the 30°R range out-of-pile and the differential in temperature of the three thermocouple positions was recorded.

The forward thermocouple (TC-1) was 0.5°R colder than the midpoint thermocouple (TC-2) and 1.5°R colder than the aft thermocouple (TC-3). The loop was then inserted to the test position in beam port HB-2 during reactor operation to determine the effect of gamma heating on the specimen temperature distribution. After stabilization of the loop temperature in-pile, the forward thermocouple (TC-1) registered 4°R lower than the midpoint thermocouple (TC-2) and 5°R lower than the aft thermocouple (TC-3). This temperature spread is considered acceptable. During the in-pile testing program, the midpoint of the specimen gage length is maintained between 30°R and 31°R.

The final step in the calibration procedure, the establishment of temperature controller sensor readings which will insure a test specimen temperature of 30°R, was accomplished with the loop in-pile after the temperature distribution measurements had been

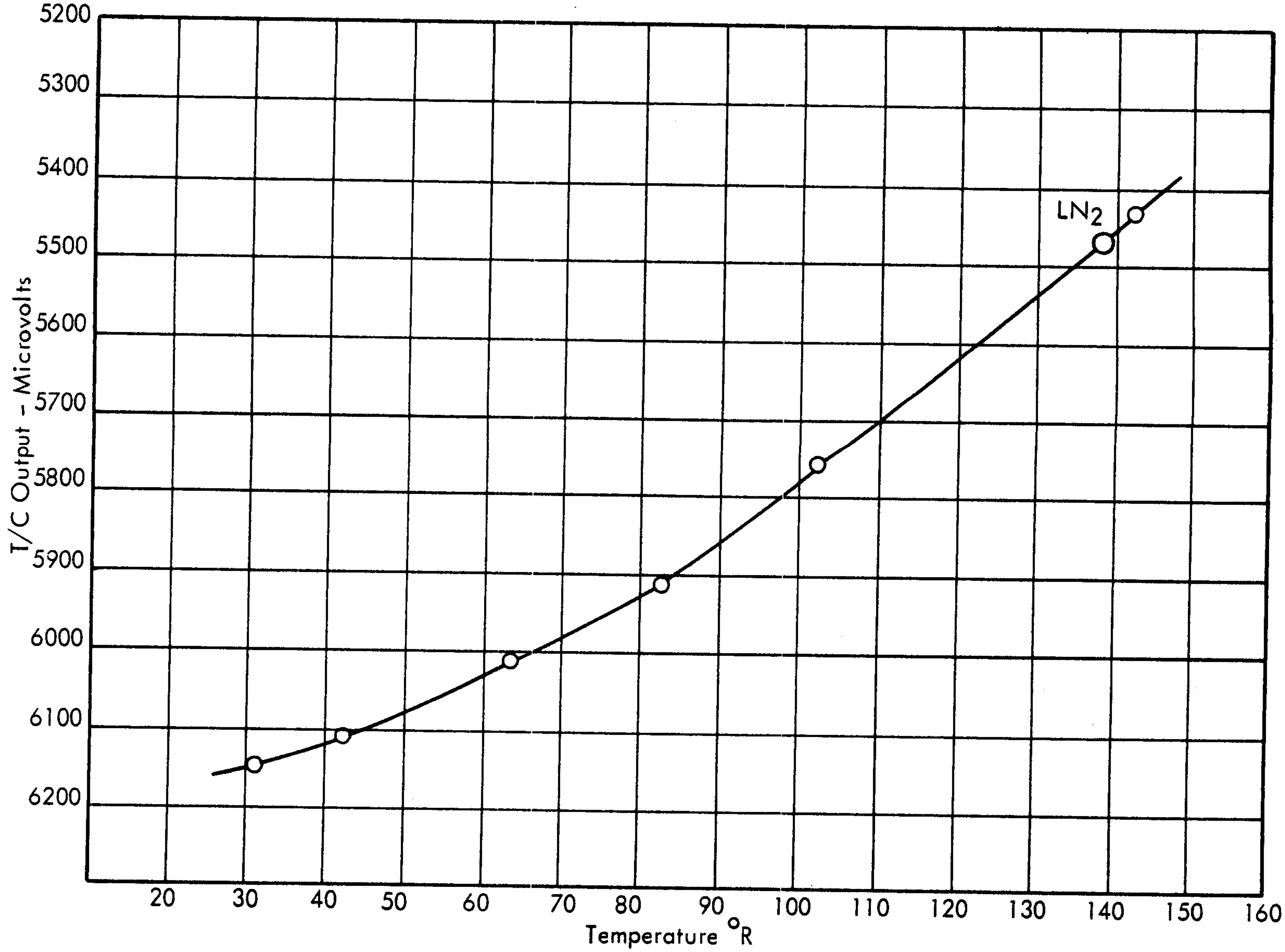

FIGURE 1 CALIBRATION CURVE FOR TITANIUM (6 Al, 2-1/2 Sn) INSTRUMENTED SPECIMEN THERMOCOUPLE NO. 1

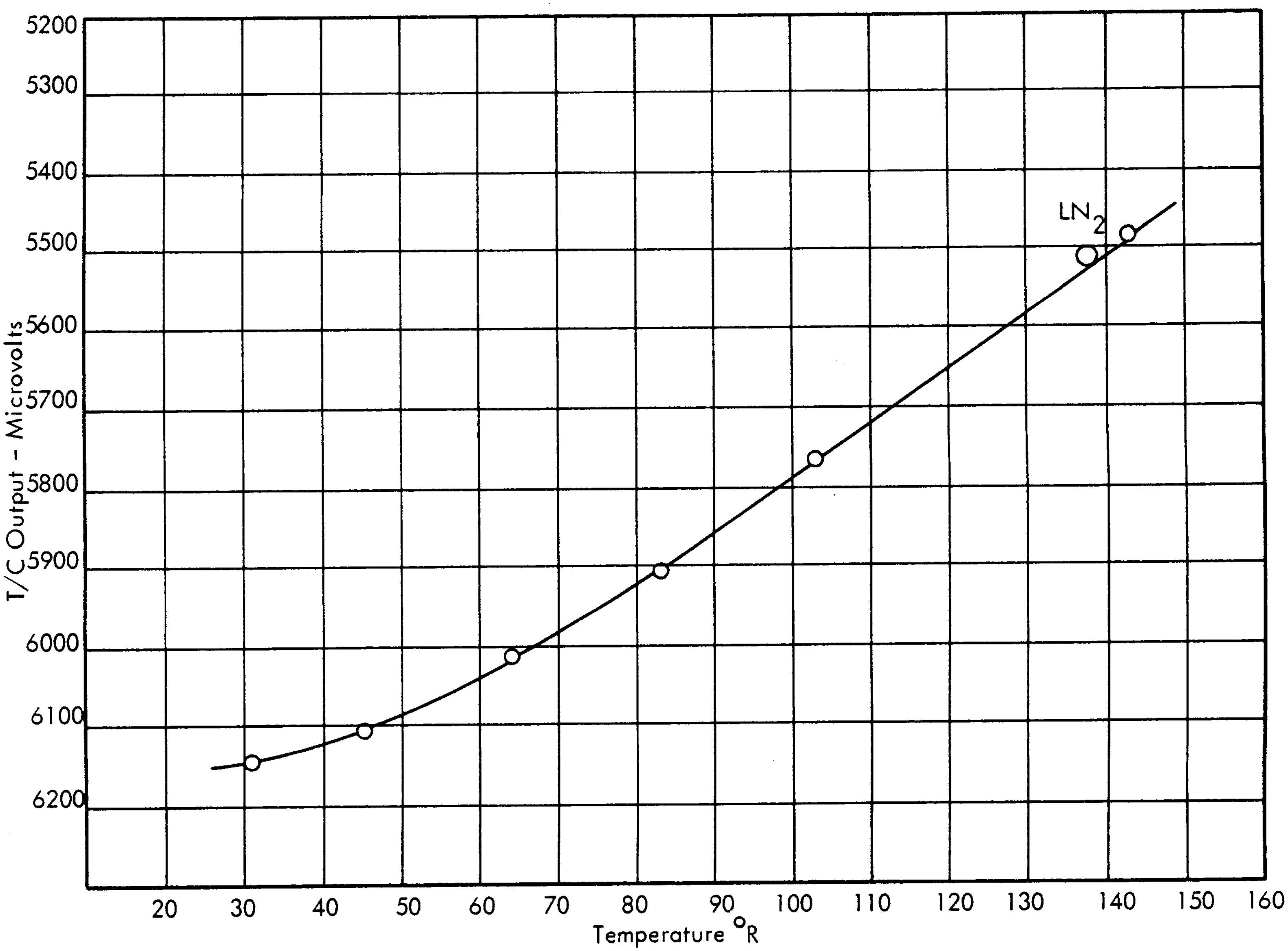

FIGURE 2 CALIBRATION CURVE FOR TITANIUM (6 Al,2-1/2 Sn)
INSTRUMENTED SPECIMEN THERMOCOUPLE NO. 2

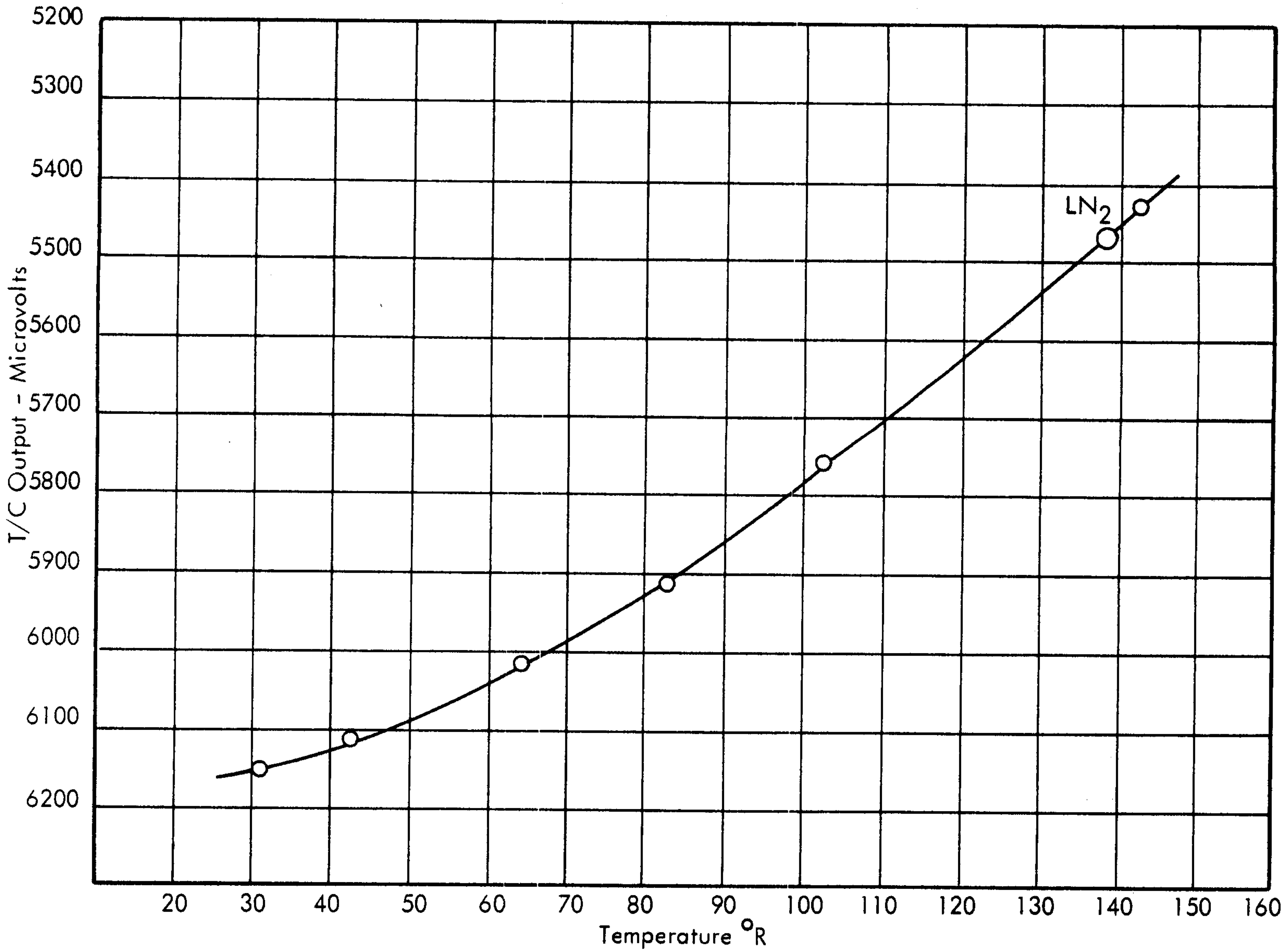

FIGURE 3 CALIBRATION CURVE FOR TITANIUM (6 Al, 2-1/2 Sn)
INSTRUMENTED SPECIMEN THERMOCOUPLE NO. 3

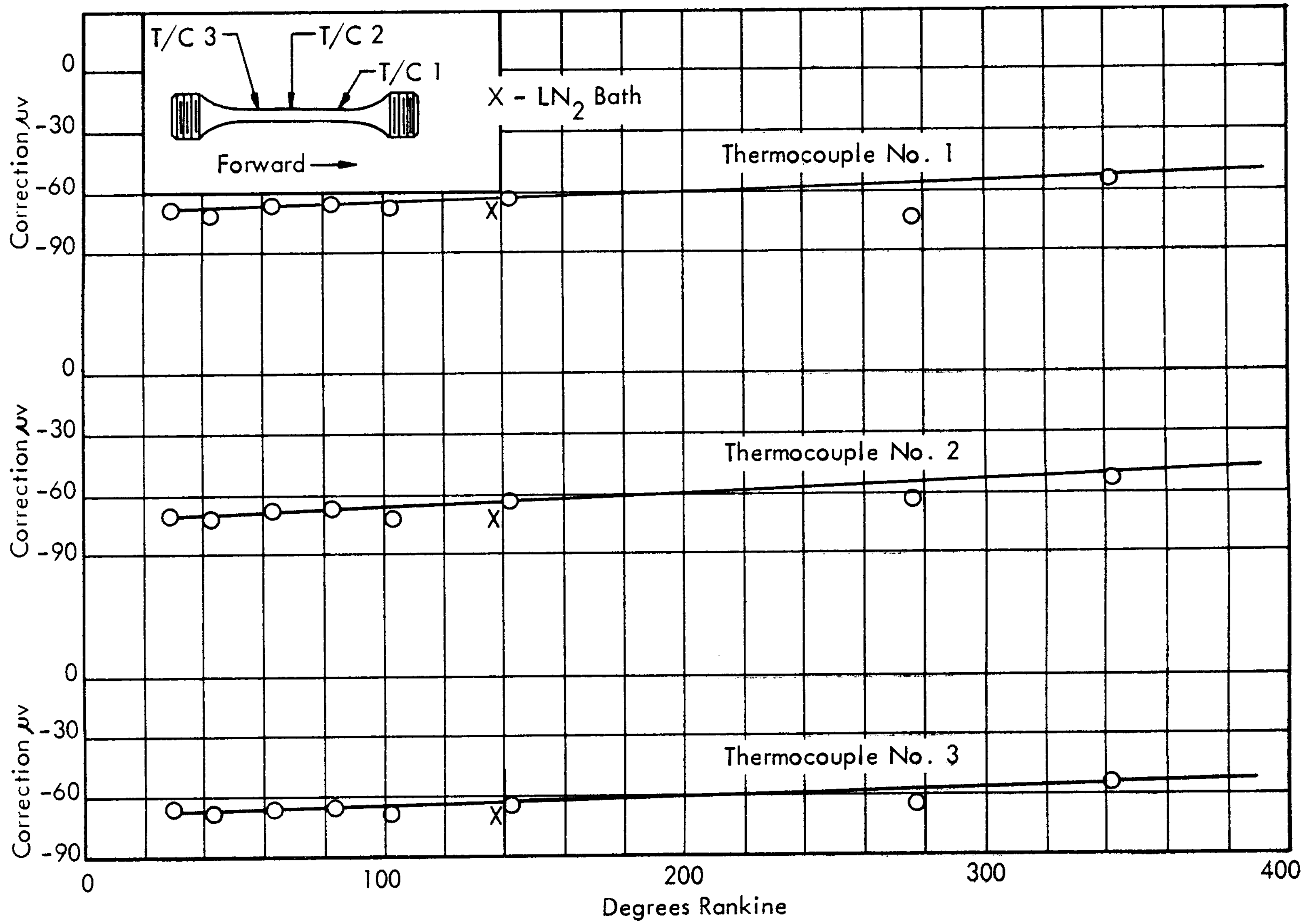

FIGURE 4 CORRECTION FACTORS FOR TITANIUM INSTRUMENTED SPECIMEN THERMOCOUPLES 1, 2, & 3

completed. Under steady-state conditions, with refrigeration capacity balancing the gamma heating rate, the refrigeration control system temperatures were correlated with the emf output of the thermocouples located on the test specimen. This correlation is being applied to measured temperatures during in-pile testing.

2.3 REFRIGERATION SYSTEM

The operation of the refrigeration system during this period, after over 3000 hours of use, was somewhat erratic due to difficulties in the expansion engines. The first problem arose when the expansion engines could not be started after shut-down until the internal temperature had risen to about 400°R. The engines were removed, and it was found that oil had passed through the valve stuffing boxes and collected on the valve stems. When the valves were cold the oil became sufficiently viscous to prevent proper valve action. The oil was removed from the rods and the valve stuffing boxes were cleaned. The end cap was loose on three of the four intake valves making it necessary to replace these valves.

Later, erratic control of the expansion engines in engine pod #1 prompted a quite thorough investigation. Several leaks in the energy absorbing equipment were repaired and the pump was replaced as a means of eliminating possible contributing factors.

The valves again started to stick, causing difficulty in starting the engine until a temperature of 400°R had been reached. The valve stuffing was replaced in the valve stuffing boxes in both engine pods as it was felt that even after cleaning sufficient residual oil might be present in the valve stuffing to cause improper valve action.

A broken piston rod in an expansion engine later caused another operational delay. This rod had only 200 hours of operating time at failure. The failure occurred at the clamping position. All valve rods and remaining piston rods were ultrasonically inspected for possible internal discontinuities which might lead to failure. This inspection revealed no indications of incipient failure. A broken exhaust valve spring, found during disassembly, was replaced when the unit was reassembled.

Further in-pile testing was accomplished with only the engines in engine pod #2 in operation. This decision was made since the test specimen temperature could be maintained using only engine pod #2. The behavior of the engines in pod #1 was still not considered sufficiently dependable to risk the loss of a test specimen in the event of a malfunction.

Present plans are to re-start the engines in pod #1 during the shutdown period which extends into the next reporting period and determine the cause for the erratic behavior of the engines so that all engines will be reliably operable during the next reactor cycle.

2.4 BEAM PORT SHIELD

During this reporting period, the Mallory 1000 stud used to secure the shield plug was re-threaded to a 7/16-20 thread configuration by using remote handling techniques. This problem and proposed solution was discussed in Quarterly Progress Report #11, Page 4. A technique of applying a suitable nickel plating by a remote process was considered to be beyond the present state-of-the-art, in view of the fact that the original plating which had been applied under much more ideal conditions had not suitably adhered to the threaded portion of the Mallory 1000 material. Therefore, the stud was allowed to remain in the unplated condition.

The 3/4 inch thick Mallory 1000 shield plug was modified and installed on the re-threaded stud. All test operations to date have been accomplished with this plug in the shield.

2.5 REMOTE HANDLING EQUIPMENT - SAMPLE CHANGE SYSTEM

Two test loop carriages have been modified to the design described in Quarterly Progress Report #11, Page 16. As a test to assure adequacy of the design, both of these carriages were used to insert a test loop into the beam port five times against reactor system pressure without the reactor in operation. The carriages were then judged operational and used in actual in-pile tests. Components have been fabricated to assembly the remaining two carriages to the same design configuration.

The rubber chevron seals in the beam port have indicated a tendency to "roll" as a test loop is inserted. This causes severe damage to the three inner seals which are positioned so that they face outward. The force required to insert a test loop into the beam port is, in part, a function of the condition of the seals. Since the hydraulic pressure supplied to the motor is also a function of this force, an increase in the required hydraulic pressure required to drive a test loop into the beam port indicates deterioration of the seals, thus requiring a change. When it is necessary, these seals are changed by remote means. The use of polyurethane seals with thicker lips, in place of the present natural rubber seals, is being investigated as a means of obtaining a longer life expectancy.

Difficulties were encountered with the 10HP Clevite pump which operates the hydraulic system. One, which rendered the pump inoperative, was a failure of a valve spring after 171 operational hours. This pump was replaced with a similar 10HP pump on loan from the Clevite Corporation which operated during this period for 312 hours without mechanical failure. The other difficulty, a seal failure, was encountered earlier in the reporting period but did not cause shut-down. After a short period of operation, the seal which separates the lubrication system of the pump from the demineralized water hydraulic fluid failed, allowing an admixture of oil and high pressure water. The high pressure water forced the oil out of the pump crankcase, leaving only a residual film to provide lubrication. This seal failure occurred in both the regular pump and the pump on loan from the Clevite Corporation for operation during the repair of the failed valve spring. The pumps were kept in operation by refilling the crankcase frequently during use. The Clevite Corporation is investigating both incidents and hopes to provide remedial design corrections.

The present design of the system utilizes the 10HP Clevite pump to provide water to monitor leakage through the chevron seals at HB-2, thus requiring continuous operation while a test loop is in-pile. Since the in-pile exposure time required to accumulate an integrated dose of 1×10^{17} nvt on the test specimen is longer than originally contemplated, an auxiliary pressurizing system for the chevron seal is now being designed. In this sytem, a smaller pump will provide the pressure required at the chevron seal to prevent reactor primary water from mixing with quadrant water in the event of seal leakage. The 10HP Clevite pump will be required only for movement of the loops or transfer system. Since operation of the transfer system is now only a small fraction of irradiation time, this will greatly prolong the life of the Clevite pump.

The polyurethane seals in the 6" slide type gate valves used to shut off the beam port and the hot cave port, are still in excellent condition as far as can be determined by visual examination. The valves function properly with no evident leakage.

The hydraulic motors used on the carriages to drive the test loop into the beam port or hot cave port have functioned satisfactorily during operation to date, although an adequate seal to prevent water from leaking into the oil reservoir has also been a problem with these motors. Pressure forces most of the oil out of the reservoir but leaves a sufficient amount clinging to the components to provide adequate lubrication. One of the motors had previously been tested for an hour under full load conditions with no oil in the reservoir. There were no ill effects from this test; therefore, this condition is not considered to be detrimental. Operation to date has substantiated this conclusion. Bleed lines from the oil reservoir of each motor to a catch basic on the 0'-0" level have been installed to prevent oil contamination of quadrant water.

3 FLUX MAPPING

The spectral measurements of the fast neutron flux reported in Quarterly Report #11 were continued during this reporting period. The previous measurements indicated that the 3/4" Mallory 1000 shield plug would provide the most desirable fast neutron, thermal neutron and gamma population ratios. This shield plug was installed and has been in place during all flux mapping conducted during the reporting period.

Three sets of foils, as shown in Table 1, were used to obtain the fast flux spectrum at the test specimen position in HB-2 beam port. Each set of foils was irradiated for 30 minutes. They were then removed from the test loop and shipped by air to Georgia Nuclear Laboratories at Dawsonville, Georgia, where they were counted and evaluated in accordance with standard Lockheed techniques.

The results of these evaluations are presented in Figure 5. The curves in Figure 5 show a variation in flux level of approximately a factor of 2 at the 0.5 Mev neutron energy level. Examination of the condition of the several reactor operational variables at the time of the foil runs indicates that the change in flux level is a function of fuel control rod position.

These fuel control rods consist of cadmium encased in AISI Type 304 stainless steel in the upper portion. The lower portion consists of fueled segments of aluminum clad aluminum-enriched uranium alloy elements of the MTR type. The rods are progressively inserted into the core, from the bottom, during reactor operations, so as poison is removed from the core, fuel is added. One such rod is located in lattice positions LC-6, located directly in front of HB-2. This results in a rod shadowing effect and causes the significant variation in flux level.

To establish the fast neutron flux level as a function of fuel control rod position, five additional foil sets containing only Np^{237}, Th^{232} and S foils were run at several rod positions. Figure 7 presents

TABLE 1

FOILS USED IN SPECTRAL MEASUREMENTS OF FAST NEUTRON FLUX IN HB-2

Type of Foil	Nominal Weight	Nuclear Reaction	Threshold Energy
Neptunium 237	20 micrograms	$Np^{237}(n, f)Ba^{140}$	0.75 Mev
Thorium 232	50 micrograms	$Th^{232}(n, f)Ba^{140}$	1.75 Mev
Sulfur	50 micrograms	$S^{32}(n, p)P^{32}$	2.9 Mev
Nickel	0.1 gram	$N^{58}(n, p)Co^{58}$	5 Mev
Magnesium	0.5 gram	$Mg^{24}(n, p)Na^{24}$	6.3 Mev
Aluminum*	0.5 gram	$Al^{27}(n, d)Na^{24}$	8.1 Mev

* The $Al^{27}(n, p)Mg^{27}$ reaction with a threshold energy of 5.3 Mev is not included due to the short (9.8 m) half life of the product.

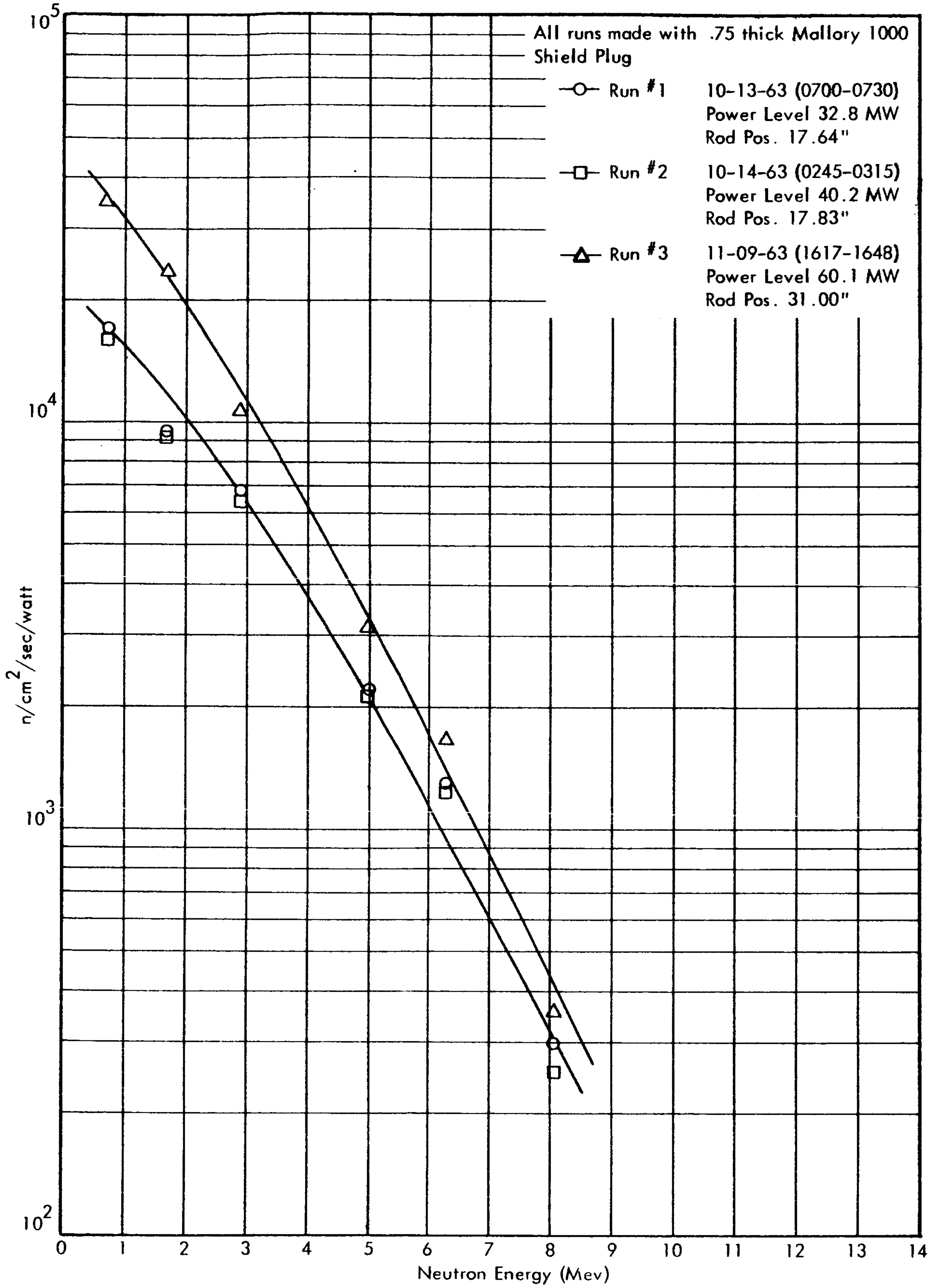

FIGURE 5 FAST NEUTRON FLUX MEASUREMENTS AT TEST SPECIMEN POSITION IN HB-2 BEAMPORT

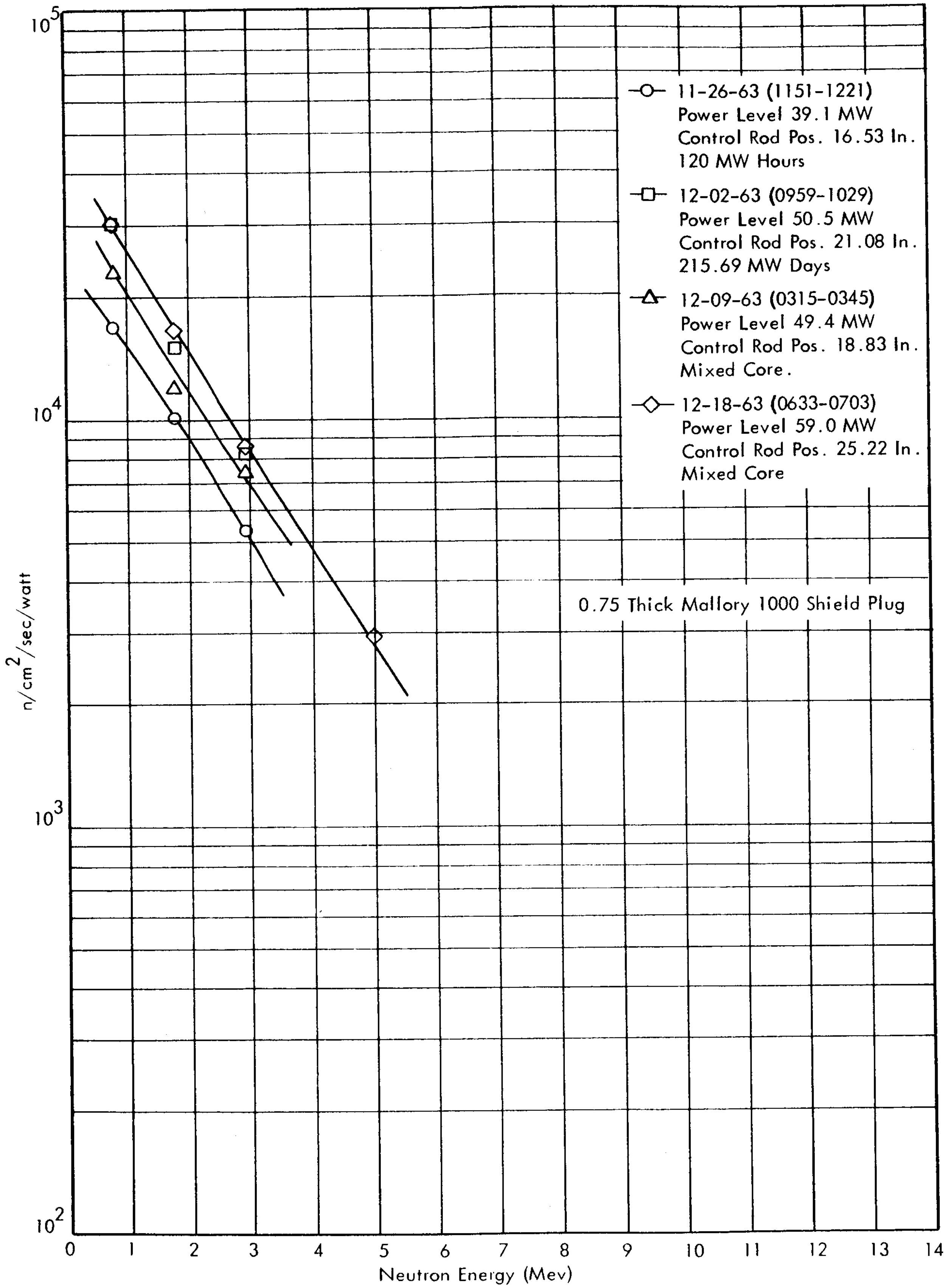

FIGURE 6 FAST NEUTRON FLUX MEASUREMENTS AT TEST SPECIMEN POSITION IN HB-2 BEAM PORT

the flux level at 0.75 Mev, measured with the Np^{237} foils, as a function of control rod position. Figure 8 presents the flux level at 0.5 Mev, extrapolated from the foil curves, as a function of control rod position.

Since the fission chambers on loops 201-002 and 201-003 became inoperative due to water damage during this reporting period, the fast neutron dose received by the test specimen was determined by calculation based on the ϕ_f obtained from Figure 8, the reactor power level, and irradiation time.

The control rod positions are recorded in the reactor operations log on an hourly basis. With this rod position the neutron flux per $cm^2/sec/watt$ is obtained from Figure 8. The reactor power level is also available on an hourly basis so that the hourly incremental increase in the dose received by the test specimen is obtained from calculations made by using these factors. The results of the calculation are adjusted for each change in a parameter until the specimen has received an integrated dose of 10^{17} nvt ($>$ 0.5 Mev) at which time the tensile load is applied to the specimen.

Examination of the test data presented elsewhere in this report shows that several specimens were exposed to integrated neutron fluxes somewhat in excess of 1×10^{17} nvt, due to in-pile exposure time calculations based on incomplete foil data.

Additional foil runs will be made during Cycle 10P and 11P, in the next quarter, to establish additional points on the high slope portion of the curve in Figure 8.

Figure 9, a curve presenting the ratio of the flux with a neutron energy level greater than 0.5 Mev to fluxes of other energy levels, is given as a base of comparison of NASw-114 test data with data from other sources.

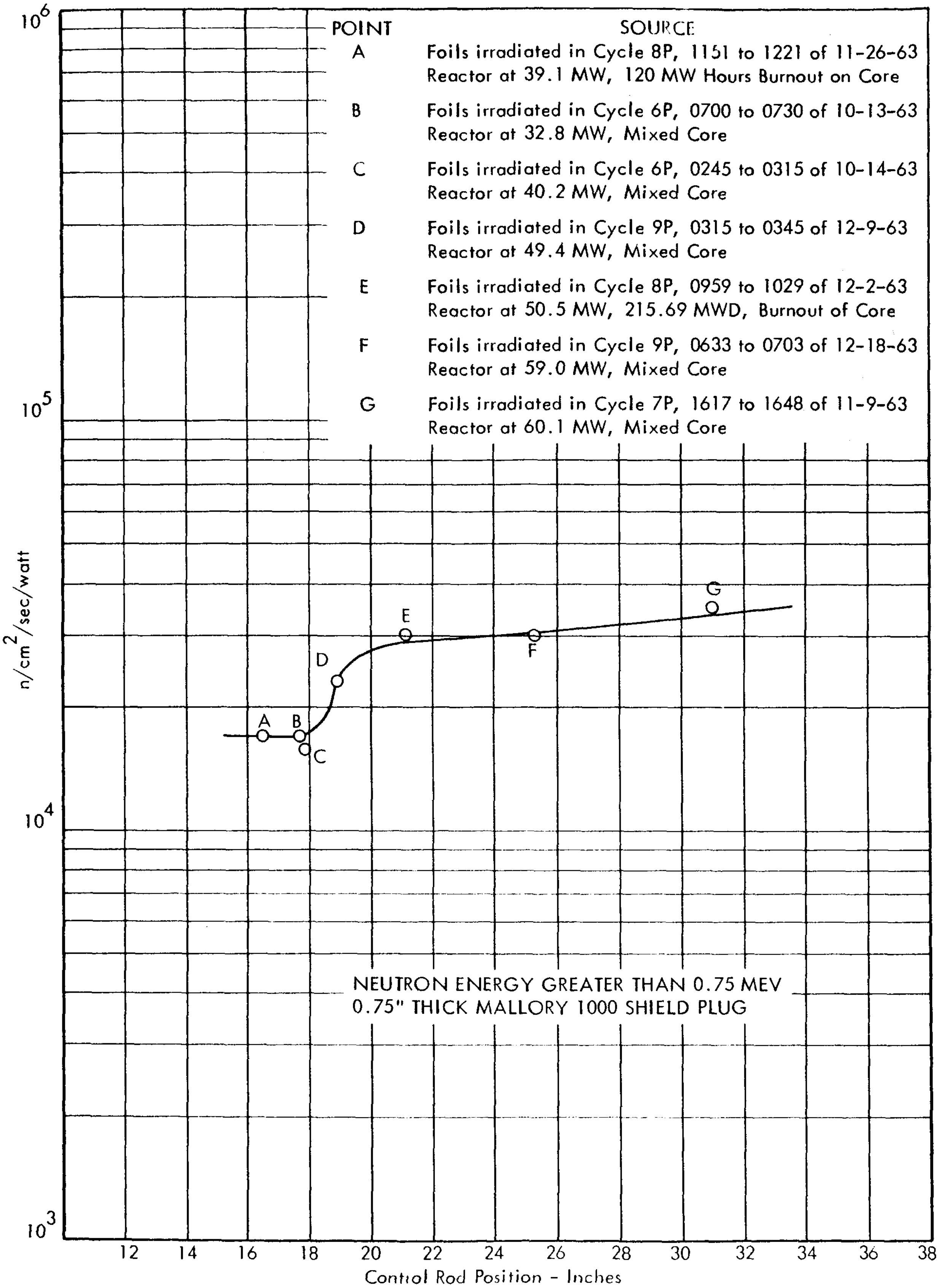

FIGURE 7 FAST NEUTRON FLUX AT TEST SPECIMEN POSITION IN HB-2 VERSUS FUEL CONTROL ROD POSITION

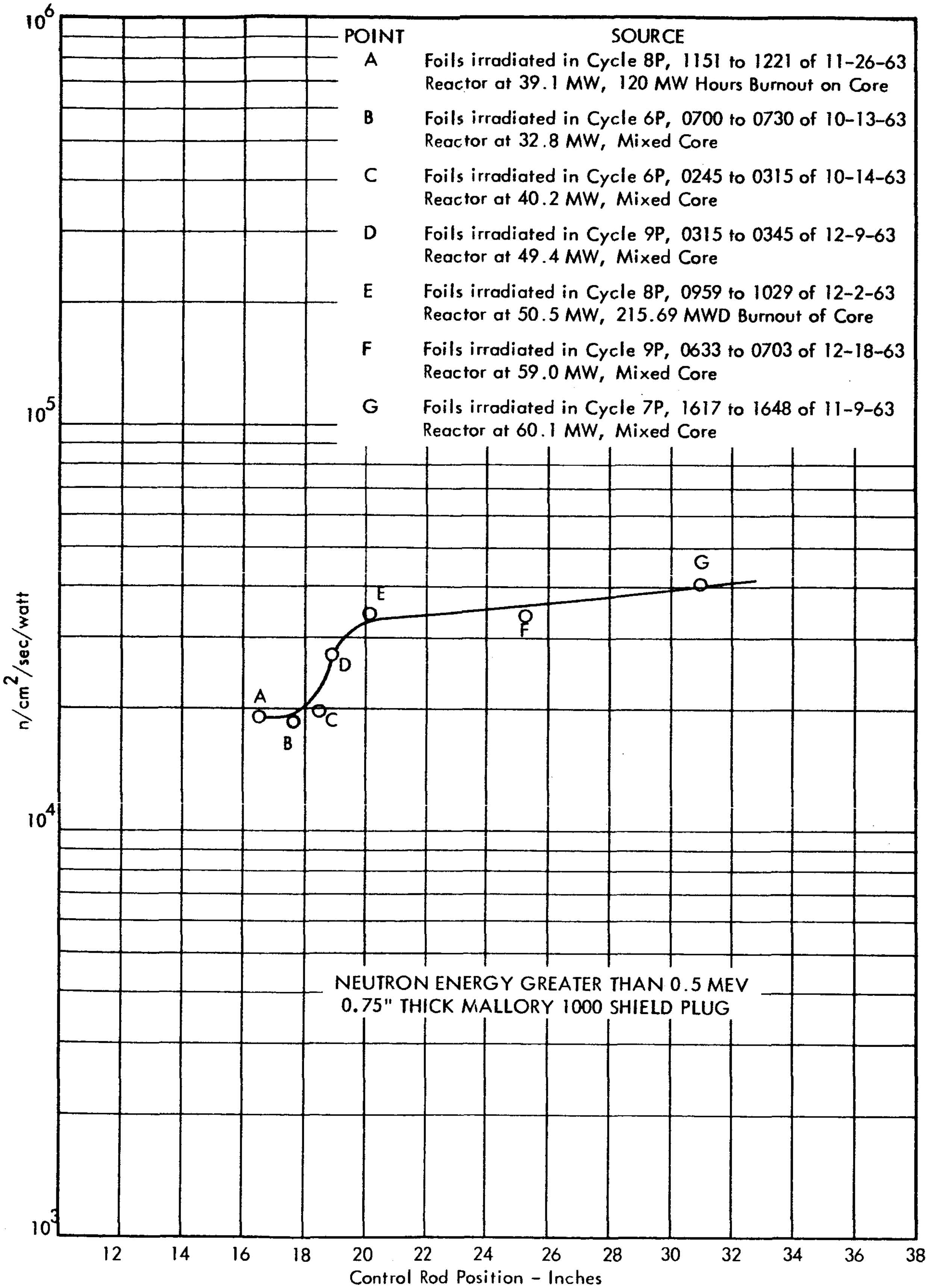

FIGURE 8 FAST NEUTRON FLUX AT TEST SPECIMEN POSITION IN HB-2 VERSUS FUEL CONTROL ROD POSITION

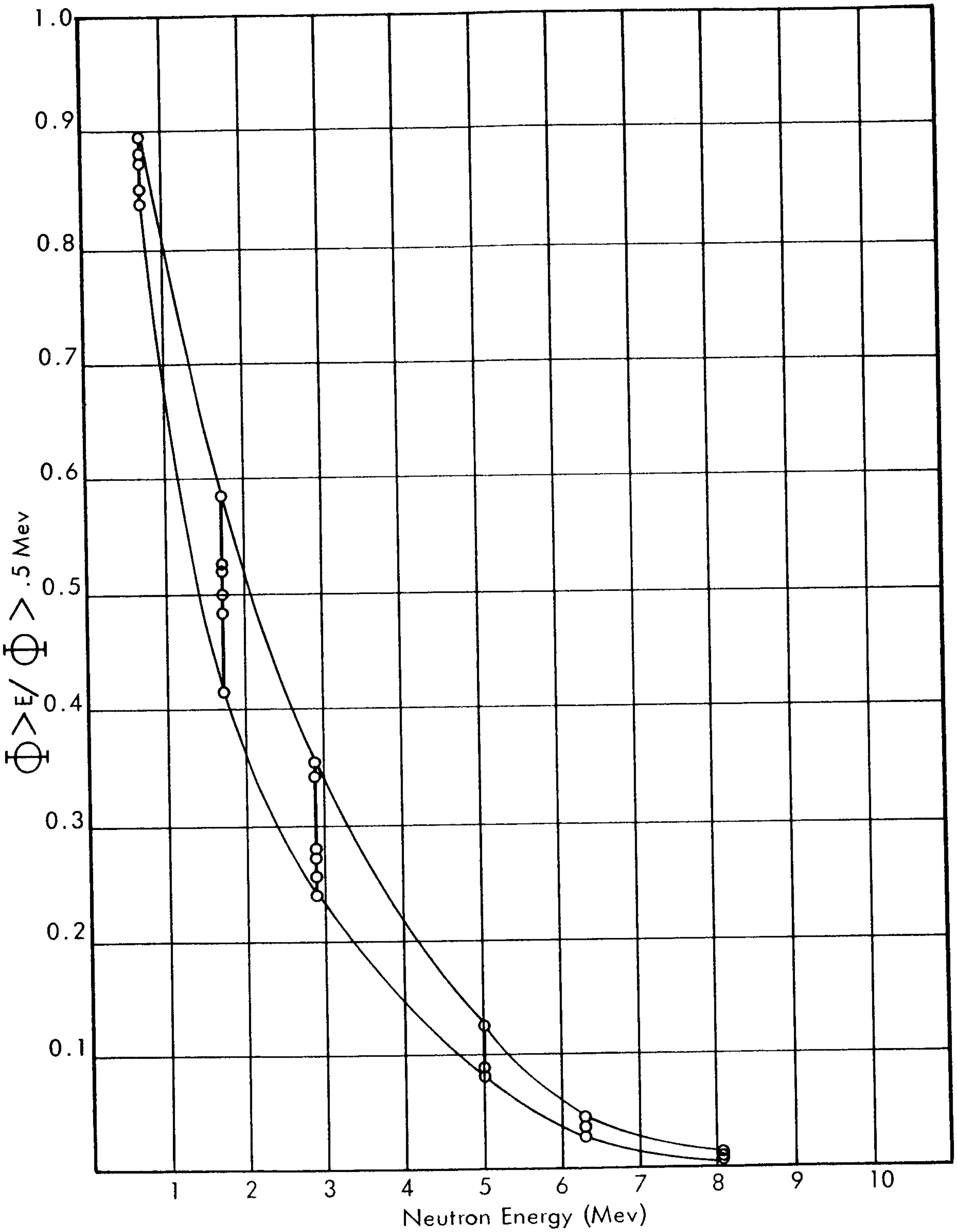

FIGURE 9 Φ>E/Φ>.5 MEV AS A FUNCTION OF NEUTRON ENERGY

4 TESTING PROGRAM

4.1 IN-PILE TESTING

The first in-pile tests at 30°R were conducted during the period covered by this report. The material selected for the initial in-pile testing was AISI Type 304 stainless steel. This is the principal structural material used in the manufacture of the experiment's test loops and it was deemed advisable to determine the possibility of deleterious radiation effects on this alloy before the loops had acquired an extensive history of exposure in a high neutron environment. Although ductility measurements are not as yet available, the results of the in-pile testing of AISI Type 304 indicate, as expected, that it is probably a suitable material for this type of nuclear application.

The number of in-pile tests presently required by NASw-114 on AISI Type 304 were completed during this reporting period. The necessity of in-pile tests of additional specimens will be determined after the final data analysis has been made. The out-of-pile tests on this alloys had been completed at an earlier date and were reported in Quarterly Report #9. The results of in-pile tests and a summary of all test results obtained on AISI Type 304 stainless steel are given in Tables 2 and 3. Ductility measurements are not available at this time. Due to the wide scatter of the in-pile tensile notch results, additional testing will be undertaken on this type of specimen during the ensuing quarter.

The large increase (150%) of ultimate tensile strength coupled with the relatively modest increase (18%) of tensile yield strength in AISI Type 304 tensile specimens tested at 30°R out-of-pile from the room temperature properties is consistent with published data for this alloy. The radiation induced hardening resulting from exposure to a neutron environment increased the ultimate tensile strength 9% and the tensile yield strength 24% at 30°R.

The tensile notch specimen showed an increase of 57% in ultimate tensile strength between room temperature and 30°R. The increase

TABLE 2

TEST DATA FOR AISI TYPE 304 STAINLESS STEEL (2 Cb) - MINIATURE TENSILE TESTS

Specimen Number	Test* Temperature (^oR)	Total Accumulated Fast Neutron Dose (nvt)	Ultimate Tensile Strength (F_{ty} in psi)	Tensile Yield (2% offset) (F_{ty} in psi)	Elongation (% in 1/2")
2 Cb 229	30	1.8×10^{17}**	258,000	53,600	***
2 Cb 265	30	1.9×10^{17}**	259,000	52,200	***
2 Cb 245	30	1.9×10^{17}**	267,000	53,300	***
Average	-	-	261,000	53,000	***
Scatter	-	-	±1.7%	±1.3%	***

Test Conditions	Average Ultimate Tensile Strength (F_{tu} in psi)	Average Tensile Yield Strength (0.2% offset) (F_{ty} in psi)	Average Elongation (% in 1/2")
Room Temp., Out-of-pile	95,200	36,800	80
30^oR, Out-of-pile	239,800	42,700	36
30^oR, In-pile*	261,000	53,000	***

* See Section 2.2, Page 5, for method of temperature control.

** Overexposure due to lack of accurate flux data at time of test.

*** Not currently available.

TABLE 3

TEST DATA FOR AISI TYPE 304 STAINLESS STEEL (2 Cb)
MINIATURE TENSILE NOTCH TESTS

Specimen Number	Test Temperature* (^{O}R)	Total Accumulated Fast Neutron Dose (nvt)	Ultimate Tensile Strength (F_{tu} in psi)
2 Cb 292	30	1×10^{17}	203,000
2 Cb 295	30	1.4×10^{17}**	157,000
2 Cb 269	30	1.12×10^{17}**	228,000
Average	-	-	196,000***
Scatter	-	-	±20%

Test Conditions	Average Ultimate Tensile Strength (F_{tu} in psi)
Room Temp., Out-of-pile	106,300
$30^{O}R$, Out-of-pile	167,600
$30^{O}R$, In-pile	196,000****

* See Section 2.2, Page 5, for method of temperature control.

** Overexposure due to lack of accurate flux data at time of test.

*** Due to wide scatter, additional tests will be performed and reported at a later date.

**** This value subject to revision based on additional tests to be undertaken at a later date.

in tensile strength caused by radiation induced hardening at $30^{o}R$ was found to be 16%. However, the average in-pile test results will be further evaluated after additional tests have been performed to explain or reduce the excessively wide scatter band of the test data.

The second material selected for testing during the in-pile screening program was AISI Type 347 stainless steel. This was considered a suitable material for testing in conjunction with AISI Type 304 since both materials are modifications of the same basic alloy. Tensile testing of the AISI Type 347 was completed during this report period; one tensile notch test is still pending and will be completed in the next quarter. The out-of-pile tests on this alloy had been completed at an earlier date and reported in Quarterly Report No. 9. The results of the in-pile tests and a summary of all results obtained on AISI Type 347 stainless steel are given in Tables 4 and 5. As previously stated, ductility measurements are not as yet available and will be reported at a later date.

The results of the tensile tests are consistent with the results of tensile tests of AISI Type 304. The increase in ultimate tensile strength out-of-pile at $30^{o}R$ was 151% and the increase due to radiation effects at $30^{o}R$ was 5.6%. The increase in yield strength out-of-pile at 30^{o} was 16% and the radiation induced hardening increased this value at $30^{o}R$ by 21%.

The tensile notch specimen showed an increase in ultimate tensile strength of 100% at $30^{o}R$ out-of-pile and a radiation induced increase of 7-1/2%, based on the incomplete results available at the end of this reporting period.

Designation of a mechanism to account for the magnitude of the changes in mechanical properties in these austenitic stainless steels must be deferred until the elongation and reduction of area measurements are available, as the existence of any significant change in ductility is of considerable important in the formulation of such a model.

TABLE 4

TEST DATA FOR AISI TYPE 347 STAINLESS STEEL (4 Cb) - MINIATURE TENSILE TESTS

Specimen Number	Test* Temperature (^{o}R)	Total Accumulated Fast Neutron Dose (nvt)	Ultimate Tensile Strength (F_{ty} in psi)	Tensile Yield (.2% offset) (F_{ty} in psi)	Elongation (% in 1/2")
4 Cb 39	30	2.1×10^{17}**	277,000	69,000	****
4 Cb 43	30	1.05×10^{17}	230,000	61,000	****
4 Cb 44	30	0.93×10^{17}***	246,000	59,200	****
Average	-	-	251,000	63,000	****
Scatter	-	-	± 9.5%	± 8%	****

Test Conditions	Average Ultimate Tensile Strength (F_{tu} in psi)	Average Tensile Yield Strength (0.2% offset) (F_{ty} in psi)	Average Elongation (% in 1/2")
Room Temp., Out-of-pile	94,400	44,900	58
$30^{o}R$, Out-of-pile	237,700	52,200	42
$30^{o}R$, In-pile*	251,000	63,000	****

* See Section 2.2, Page 5, for method of temperature control.
** Overexposure due to lack of accurate flux data at time of test.
*** Exposure terminated due to irrecoverable reactor scram.
**** Not currently available.

TABLE 5

TEST DATA FOR AISI TYPE 347 STAINLESS STEEL (4 Cb)
MINIATURE TENSILE NOTCH TESTS (INCOMPLETE)

Specimen Number	Test Temperature* (^{o}R)	Total Accumulated Fast Neutron Dose (nvt)	Ultimate Tensile Strength (F_{tu} in psi)
4 Cb 27	30	1.18×10^{17}	244,000
4 Cb 54	30	1.19×10^{17}	265,000
Average (2 only**)	-	-	254,500
Scatter	-	-	$\pm 8.5\%$

Test Conditions	Average Ultimate Tensile Strength (F_{tu} in psi)
Room Temp., Out-of-pile	112,900
30^{o}R, Out-of-pile	227,000
30^{o}R, In-pile*	254,500

* See Section 2.2, Page 5, for method of temperature control.

** One additional specimen will be tested during Reactor Cycle 10P.

4.2 DATA RECORDING

A typical stress-strain diagram recorded during the in-pile testing of the austenitic stainless steel at 30°R is shown in Figure 10. This curve was obtained from an AISI Type 347 sample tested in-pile at 30°R.

Due to design limitations, the extensometers used for strain measurement during tensile testing have a reliably accurate operating range of only approximately 0.010 inch which is 2% of the 0.500" specimen gage length. This is sufficient to provide automatic recording on the X-Y plotter of the elastic portion of the stress-strain curve and a segment of the plastic portion, the extent of which is dependent on the modulus slope but cannot exceed 2% total strain. For this reason, a complete stress-strain diagram from application of the load to failure cannot be obtained with project equipment; after 2% total strain, only stress is recorded. Fluctuations of stress during testing which occur after the extensometer no longer measures strain are recorded by manual manipulation of the X axis pen and the abscissa divisions between stress variations are arbitrary and not related to strain.

In in-pile testing of austenitic stainless steels, considerable fluctuation of stress level was observed during the portion of the tests in which strain was not recorded. The irregular segment in the left side of Figure 10 shows the number and stress magnitude of these events. Complete stress-strain curves for austenitic stainless steel tested at cryogenic temperatures in the NBS Cryogenic Engineering Laboratory at Boulder, Colorado, (NBS PB 171809-3, Dec. 1961) show similar stress fluctuations during plastic behavior, so this phenomenon has been encountered in cryogenic environments and it is not as yet known if irradiation has any effect on the number or size of these stress fluctuations.

4.3 OUT-OF-PILE TESTING

During the period covered by this report, out-of-pile testing was resumed on a limited basis. This testing was principally performed

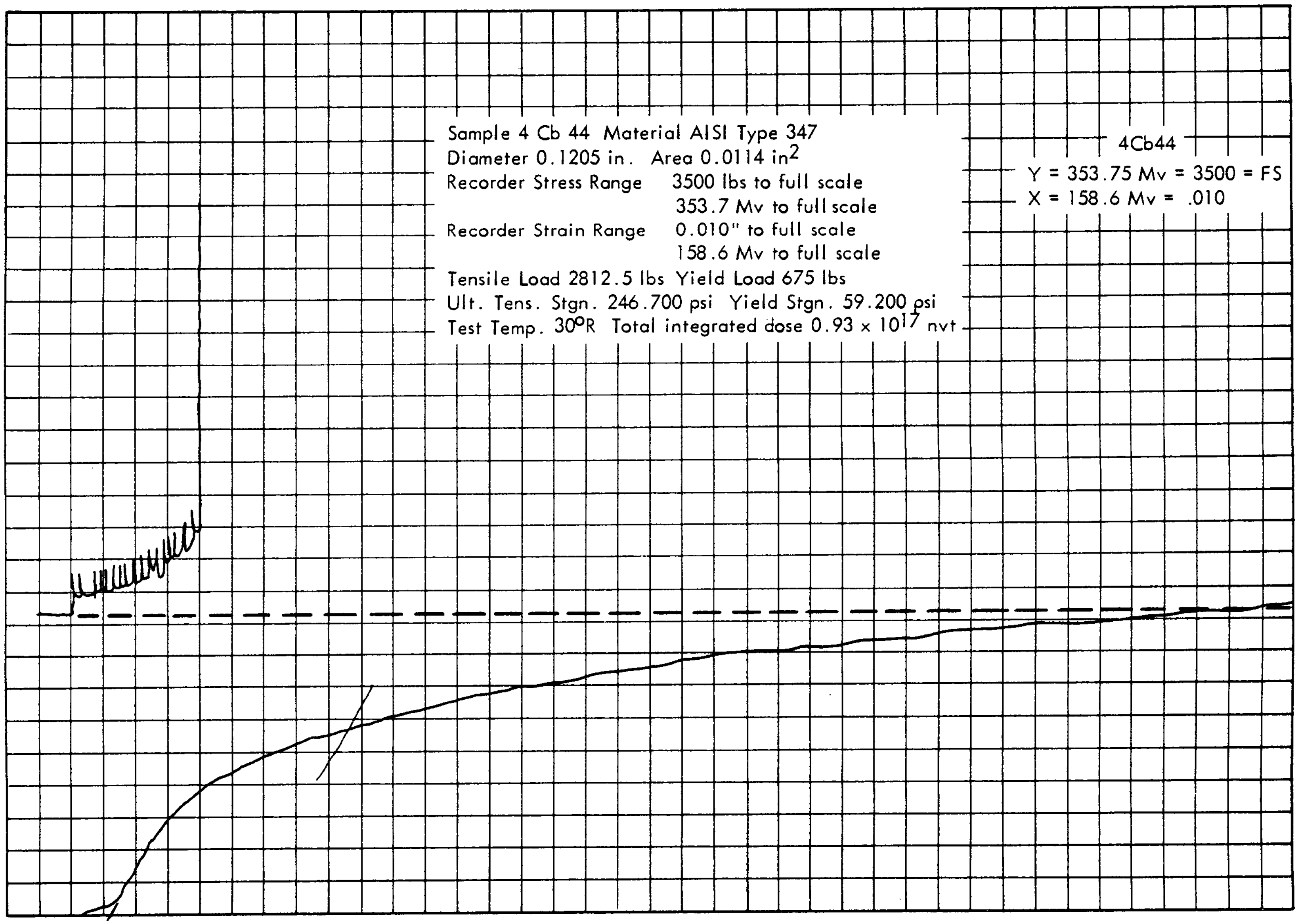

FIGURE 10 STRESS-STRAIN DIAGRAM OF TENSILE SAMPLE

in test loops inserted in the hot cave with specimen changes accomplished by remote handling to provide operator training and allow refinement of remote tooling and techniques. The primary purpose of the resumption of out-of-pile testing at this time was training rather than rapid generation of test data. Scheduling of out-of-pile tests was restricted by access to the hot cave and availability of otherwise uncommitted training personnel. As a result of this approach, the requisite out-of-pile tests have not been completed for any of the new materials.

APPENDIX A

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